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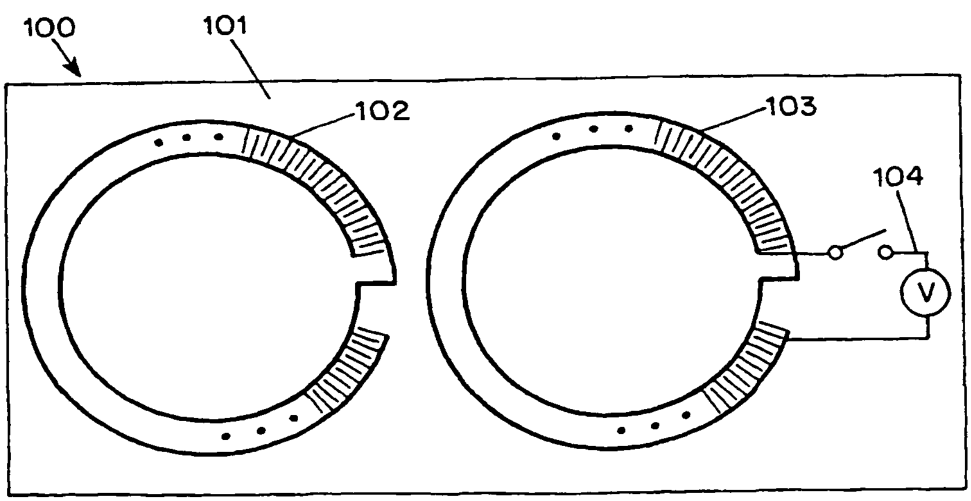
(54) Title: TUNABLE HIGH TEMPERATURE SUPERCONDUCTOR RESONATOR AND FILTER



(57) Abstract: This invention pertains to a superconducting tunable resonator and filter device operable over a broad range of frequencies including the MHZ frequency range. In one embodiment, two superconducting resonators (102, 103) are disposed on a first surface of a substrate (101) and a switch circuit (104) is connected to at least one of the resonators (102, 103) such that the switch circuit (104) is responsive to a signal having at least a first and second state which causes the switch circuit (104) to drive one of the first and second resonators (102, 103) into a non-superconducting state, thereby effecting tuning of the resonators and filter.

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TUNABLE HIGH TEMPERATURE SUPERCONDUCTOR RESONATOR AND FILTER

Field of the Invention

This invention relates to tunable resonator and filter devices and, more particularly, to such devices formed with a superconducting material.

Background of the Invention

Ever since their discovery, high-temperature superconducting (HTS) materials have been considered for use as thin-film resonators and filters, such as micro-strip or cavity structures in the GHz-frequency range in microwave communication applications. Use of HTS materials for such devices promises high Q-values due to low electrical loss. This advantage would apply also at lower frequencies, but conventional quarter-wavelength parallel-coupled designs commonly used at microwave frequencies result in prohibitively large device dimensions in the MHZ-range.

One way to realize MHZ-range resonators and filters of practicable dimension is the lumped-element approach, e.g., using discrete inductor and capacitor elements. One such structure consists of a two-turn spiral with an inter-digital capacitor between the turns. Another has two spirals and two capacitively coupled rings separated by a dielectric layer. A third includes self-resonant spirals. However, at low MHZ frequencies, the length of the conductor used to form the spirals is generally long which results in a high resistance and low circuit Q.

Tunable high frequency stripline superconductor resonators have been described by D.E. Oates et al in "Tunable YBCO Resonators on YIG Substrates" IEEE Transactions on Applied Superconductivity, Vol/ 7, N0. 2, at 2338 (June 1997) In addition, high frequency RF resonators have been discussed by Q.Y. Ma in "FR Applications of High Temperature Superconductors in MHz Range" IEEE Transactions on Applied Superconductivity (June 1999) which is incorporated herein

by reference. Filters can also be designed to operate at a single frequency of interest or at multiple frequencies. For example, a channelizer filter receives plural frequency signals on a single input port and selectively provides an output signal to one or more output ports. Of interest with respect to channelizer filters is G. Matthaei et al., "Microwave Filters, Impedance-Matching Network, and Coupling Structures", Chapter 16, Artech House, Dedham, MA, 1980.

Heretofore it has not been possible to provide low frequency RF multiple bandpass tunable resonators or filters with narrow bandwidth, high Q value, and low insertion loss.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a compact, high Q, low loss tunable resonator structure, suitable for use at frequencies down to the MHz range.

It is a further object of the present invention to provide a tunable filter employing plural superconducting resonator elements, suitable for use over a broad range of radio frequencies, including those in the MHz range.

In accordance with one embodiment, an electromagnetic resonator includes a substrate and two superconducting resonators disposed on a first face of the substrate. A switch circuit coupled to at least one of the first and second resonator elements is provided having at least two states. One of the states drives one of the first and second superconductor resonator elements to a non-superconductive state. Alternative forms of the resonator include forming the second superconductor resonator element on a second substrate. In addition, the first and second superconductor resonator elements can be comprised of a coiled interdigitated capacitor. Furthermore, the first and second superconductor resonator elements as well as the switch circuit can be formed of a superconductor material such as yttrium-barium-copper oxide.

A method of active frequency switching for a superconducting resonator is described comprised of providing two superconductor resonator elements operating in a superconducting state and electromagnetically coupled with each other

thereby forming the superconducting resonator with a first resonant frequency. An electrical control signal is applied to one of the resonator elements thereby driving one of the superconductor resonator elements into a non-superconducting state and thereby tuning the superconducting resonator to a second resonant frequency.

A tunable superconducting resonator is also described comprising a substrate, a superconductor resonator element and an actuator. The superconductor resonator element has a non-moveable portion and a moveable portion. The non-moveable portion of the superconductor resonator element is provided with an inductor and a portion of a variable capacitor formed on the substrate. The actuator has a moveable end relative to the substrate, which is moveable in response to an applied control signal. The moveable portion of the superconductor resonator element is formed on the moveable end of the actuator and is in capacitive communication with the portion of the variable capacitor formed on the substrate. The actuators can be piezoelectric actuators such as a multilayer bender actuators or tube actuators.

An alternative embodiment of the variable capacitor is described wherein the portion formed on the first face has a trunk with a plurality of tines, and the moveable portion of the superconductor resonator has a second trunk also with tines. The tines of the two structures are positioned in moveable juxtaposition to each other, thus forming a variable capacitor.

A tunable superconducting filter is described as having a substrate and a plurality of superconductor resonator elements formed on the substrate. Each of the plurality of superconductor resonator elements have a non-moveable portion and a moveable portion. The non-moveable portion is described as comprising an inductor formed on the first face and a portion of a variable capacitor also formed on the first face. A plurality of actuators are provided, each having a moveable end relative to the substrate in response to an applied control signal. Each moveable portion is mounted on the moveable end of a corresponding actuator and is in capacitive communication with a portion of a corresponding variable capacitor formed on the first face. In addition, input and output coupling structures are provided as being operatively coupled to superconductor resonator elements. The inductors of the superconductor resonator elements can be provided in an elongate geometry and be arranged in a

side-by-side relationship. The superconductor resonator elements, as well as the input and output coupling structures can be comprised of superconductive materials such as yttrium-barium-copper oxide. In addition, the tunable superconducting filter can be provided where each superconductor resonator element is resonant at substantially the same frequency or the superconductor resonator elements can be resonant at different frequencies.

Also described is a tunable superconducting device provided on a substrate and having a tunable superconductor resonator element and a coupling structure. The tunable superconductor resonator has an inductor and a portion of a variable capacitor formed on the substrate. The tunable superconducting device also has an actuator with a moveable portion of the tunable superconductor resonator element formed on the moveable end of the actuator in response to an applied control signal. The moveable portion is in capacitive communication with the portion of the variable capacitor formed on the first face. Similarly, the coupling structure has a non-moveable portion and a moveable portion. The non-moveable portion is disposed on the substrate and is operatively coupled to the tunable superconductor resonator element. A second actuator, with a moveable end in capacitive communication with the coupling structure, is provided for impedance matching of the tunable superconductor resonator element with a device employing the tunable superconducting device.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic top view, enlarged, of a tunable resonator according to the invention.

Fig. 2 is a schematic top view, enlarged, of an alternative configuration of the tunable resonator in Figure 1.

Fig. 3 is a graph of resonator responses for the Filter according to Fig. 1 with and without an applied voltage.

Fig. 4 is a schematic top view, enlarged, of a tunable resonator.

Fig. 5a is a perspective view, enlarged, of the tunable resonator of Fig. 4 having a bender actuator.

Fig. 5b is a perspective view, enlarged, of the tunable resonator of Fig. 4 having a tube actuator.

Fig. 6 is a schematic top view, enlarged, of an alternative configuration of a variable capacitor for the tunable resonator in Figure 4.

Fig. 7 is a schematic top view, enlarged, of a tunable resonator filter.

Fig. 8 is a schematic top view, enlarged, of a tunable resonator filter for receiving a signal and for matching impedance.

Throughout the figures, the same reference numerals and characters, unless otherwise stated, are used to denote like features, elements, components or portions of the illustrated embodiments. Moreover, while the subject invention will now be described in detail with reference to the figures, it is done so in connection with the illustrative embodiments. It is intended that changes and modifications can be made to the described embodiments without departing from the true scope and spirit of the subject invention as defined by the appended claims.

DETAILED DESCRIPTION

Fig. 1 is a plan view of a first embodiment of a tunable superconducting resonator 100. The resonator is formed on a substrate 101 and includes a first superconductor resonator 102 formed on a first face of the substrate 101, as well as second superconductor resonator 103 also formed on the first face of the substrate 101. The resonator 102, 103 are place proximate to one another such that they are electromagnetically coupled and cooperate as a common resonant structure. Alternatively, the first and second superconductor resonators can be formed on separate substrates so long as the resonators are electromagnetically coupled. A high temperature superconductor material such as yttrium-barium-copper oxide is a preferable material used for resonator fabrication and can be cooled by use of liquid nitrogen or by being placed in a cryostatic chamber. A switch circuit 104 coupled to at least one of the first and second resonators can allow an electrical control signal to be applied to at least one of the resonators. The switch circuit 104 can be formed using a conventional conductor material, such as gold wires. However, forming the switch circuit 104 from a superconductor material, such as the material used to form the first

and second superconducting resonators 102, 103, offers advantages in maintaining high circuit Q and low insertion loss.

The dimensions chosen for the structures in Fig. 1 affect the resonating characteristics of each structure. For a single resonator formed on a two inch wafer, resonant frequencies in the range of 1MHz to 4 GHz can be obtained depending on the dimension of the resonator. A resonator structure according to Fig. 1 can be fabricated having a 37mm diameter outer loop, separated from an inner loop by interdigitated fingers of 3mm length and 50μm width, each interdigitated finger separated from another by 50μm. The width of each interdigitated finger and spacing between each interdigitated finger can be reduced to 20μm. Two resonators, formed on separate substrates can be placed in proximity to one another, at 5mm at their closest points, to provide a resonator having a resonant frequency of 95.7 MHz in one state and 101MHz in another.

Fig. 2 illustrates an alternative design of the tunable superconductor resonator of Fig. 1 in which the first and second superconductor resonators 202, 203, and switch circuit 104 are fabricated on a typical substrate 201, thereby making packaging easier and making more efficient use of substrate material. The dimensions of the resonators are illustrative of the size of the resonator relative to the exemplary substrate, specifically a 2 inch LAO wafer disc, however, the dimensions of the resonator structures throughout depend upon the requisite capacitance or inductance to be generated for the resonant frequency desired.

A resonator structure according to Fig. 2 has been fabricated on a single 2 inch wafer, each resonator structure being about 10mm in width, 25mm in length and having interdigitated fingers of 3mm length and 50μm width, each interdigitated finger separated from another by about 50μm. Again, the width of each interdigitated finger and spacing between each interdigitated finger can be reduced to 20μm. Two resonators can be formed on a single substrate 101 and placed in proximity to one another, at about 2.5mm at their closest points, whereby a resonator results having a resonant frequency of about 50MHz in one state and 60MHz in another.

The switch circuit 104 provides an electrical control signal to at least one of the superconductor resonators 103. The control signal has at least first and second states, for example, a voltage of 0 Vdc and 0.2 Vdc respectively. A second control voltage can be up to 2.0 Vdc. When the control voltage is applied to resonator 103 in a first state, both superconductor resonators can remain in a superconducting state. As a consequence, the first superconductor resonator 102 can be magnetically coupled to the second superconductor resonator 103 thereby providing a superconducting resonator 100 with a first resonant frequency f_1. When the control voltage is applied to resonator 103 in the second state, the superconductor resonator 103 is driven into a non-superconductive state. By converting the superconducting resonator 103 into a non-superconductive state, the resonant frequency of the tunable superconducting resonator 100 can be changed to a second resonant frequency f_2, wherein f_2 is the resonant frequency of the superconductor resonator 102 remaining in a superconductive state. Fig. 3 shows the resonant response of the tunable resonator of Fig. 1 wherein a frequency shift from 95.7 MHz to 101 MHz can be obtained by applying no voltage and 0.2V to the resonator 103 respectively.

It is possible to obtain continuous frequency tuning by providing a tunable superconducting resonator as shown in Fig. 4. The present tunable superconducting resonator 400 includes a superconductor inductor 402 formed on a substrate 401 and a variable capacitor 403 that consists of two separated parts, a non-moveable portion 403a formed on a first face of the substrate 101 and a moveable portion 403b.

A tunable resonator according to Fig. 4 can be provided where each side of the superconductor inductor 402 is 25mm in length and 2mm in thickness, i.e., from an outer edge to an inner edge. The non-moveable portion 403a of the variable capacitor 403 can be formed of two portions of 5mm square separated by 0.5mm. The moveable portion 403b of the variable capacitor 403 can be 5mm in width and 10mm in length and separated from the non-moveable portion 403a of the variable capacitor 403 by a spacing from 1mm to 3mm.

Figs. 5a and 5b illustrate a perspective views of two alternative arrangements of a continuously tunable resonator according to an exemplary

embodiment of the present invention. As illustrated in Figs 5a and 5b, the moveable portion 403b is mounted on an actuator for controllably moving the moveable portion of the variable capacitor 403b with respect to the non-moveable portion 403a. The distance between the moveable portion of the variable capacitor 403b and the non-moveable portion 403a is from 1mm to 3mm. The actuator 502 is provided with a moveable end 503 relative to the substrate 101 in response to an applied control signal 504. The moveable portion of the variable capacitor 403b is mounted, or otherwise formed, on the moveable end of the actuator 501 and is in capacitively coupled to the non-moveable portion of the variable capacitor 403a formed on the first face of the substrate 101. Accordingly, through the application of the control signal 504, the value of the variable capacitor 403 can be changed over a continuous range by changing the relative position of the moveable part 403b to the non-moveable part 403a. The voltage of the control signal can vary from 30V to -30V depending upon the type of actuator used. Since the frequency of the resonator changes with the value of the capacitor 403, the frequency of the resonator can thereby be changed along a continuous range.

Two different embodiments of the actuator 501 for the tunable superconducting resonator are shown in Figs 5a and 5b. In Fig. 5a, a piezoelectric bender 502a is employed for the actuator. In this case, the control voltage 504 controls the motion of the piezoelectric bender which can be positioned in a direction along the plane of the substrate 101. Alternatively, in Fig. 5b, a piezoelectric tube actuator 502b is employed for the actuator 501 whereby the control voltage 504 moves the piezoelectric tube actuator vertically relative to the plane of the substrate 101. Piezoelectric multilayer bender actuators and piezoelectric tube actuators are commercially available from Polytec PI. Alternative arrangements of the actuator 502 relative to the substrate 101 can also be provided.

Shown in Fig. 6 is an alternative arrangement of the resonator shown in Figs 4 and 5. The tunable superconducting resonator 400 can be provided with a superconductor inductor 601 and a variable capacitor 602 that consists of two separated parts, a non-moveable portion 602a and a moveable portion 602b. The non-moveable portion of the variable capacitor 602a is formed on a substrate having at

least one trunk connector 604 each having a plurality of tines 603. The moveable portion of the variable capacitor 602b can include a trunk connector 604 having a plurality of tines 603 arranged such that the tines 603 are in moveable juxtaposition with the tines 603 of the non-moveable portion of the variable capacitor 602a thus forming an interdigitated capacitor structure. This alternative arrangement can provide greater range of capacitance change relative to the positioning of the moveable and non-moveable portions of the variable capacitor and hence a greater range of resonance frequency of the circuit being tuned.

A tunable superconducting filter according to the invention is shown in Fig. 7 wherein a plurality of tunable resonators, such as those shown in Figs. 4 and 5 and described above, can be used to form a tunable filter. Accordingly, a three pole filter having three tunable resonators is described as follows. In this case, three superconductor resonators 500, each having a non-moveable portion 402 and 403a and a moveable portion (not shown in Fig. 7) are provided. As described above with regard to Figs. 4 and 5, the non-moveable portion of each superconductor resonator comprises an inductor 402 formed on the first face of the substrate 101 and a non-moveable portion of a variable capacitor 403a also formed on the first face of the substrate 101. In addition, three actuators are provided consistent with those described in relation to Figs 5a and 5b. Each actuator has a moveable end 503 which is controllably moveable relative to the substrate 101 in response to an applied control voltage 504. Each resonator also has a moveable portion (not shown in Fig. 7) of a variable capacitor 403b mounted on the moveable end 503 of the actuator 502. The actuator is positioned with respect to the substrate 101 such that the moveable portion 403b (not shown in Fig. 7) is in capacitive communication with the non-moveable portion 403a of the variable capacitor formed on the face of the substrate.

Input and output coupling structures 703, 704 can be provided on either face of the substrate for sensing the resonance of the circuits. The input coupling structure 703 is operatively coupled to at least one of the superconductor resonators and at least one output coupling structure 704 is also operatively coupled to one of the superconductor resonators. The input and output coupling structures 703, 704 can be formed as metallic inductor elements or formed from a superconducting

material. However, forming the input and output coupling structures from a superconductor material, such as the material used to form the superconducting resonators 500, offers advantages in maintaining high circuit Q and low insertion loss. While the embodiment of Fig. 7 illustrates a 3-pole filter configuration, it will be appreciated that n-pole configurations are also possible, where n is the number of resonator structures employed. The choice of dimensions of the coupling structures depends on the dimensions of a corresponding superconducting resonator 500.

The device in Fig. 7 can be fabricated on a single substrate 101 where each superconducting resonator 500 is about 25mm in length, 12mm in width and 2mm in thickness from an outer edge to an inner edge. Each non-moveable portion of a variable capacitor 403a can be 3mm square and separated from one another by about 0.5 mm apart. The moveable portion of each variable capacitor 403b can be rectangular with dimensions of about 5mm by 10mm and separated from a corresponding moveable portion of a variable capacitor 403a by 1mm to 3mm. In turn, each superconducting resonator 500 can be separated from one another at their proximate sides by about 2mm. The input and output coupling structures 703, 704 can be disposed 1mm to 2mm from the inductor 402 and non-moveable portion of the variable capacitor 403a.

The tunable superconducting filter can be provided wherein each of the superconductor resonators are resonant at substantially the same frequency or are resonant at a plurality of frequencies, wherein each of the plurality of frequencies corresponds to one of the output coupling structures. Thus, according to the three-pole design shown in Fig. 7, three piezoelectric actuators can be used to tune the bandwidth and center frequency of the filter.

In another embodiment, a tunable superconducting device can take the form illustrated in Fig. 8 wherein a tunable resonator and a tunable filter can be used as a resonator or a filter in a device where high quality RF or microwave resonator or filter is needed, such as communications and magnetic resonance imaging (MRI). Accordingly, a tunable superconducting device is provided having a tunable superconductor resonator for receiving a signal, the tunable superconductor resonator having a non-moveable portion and a moveable portion. The non-moveable portion of

the tunable superconductor resonator comprises an inductor 801 formed on a first face of a substrate 101 and a portion of a variable capacitor 802 also formed on the first face of the substrate 101. The tunable superconductor resonator is made tunable by providing an actuator (not shown in Fig. 8) having a moveable end relative to the substrate in response to an applied control signal such as is illustrated in Figs 5a and 5b. The moveable portion 803 of the tunable superconductor resonator is mounted on the moveable end of the actuator (not shown in Fig. 8) and is thereby capacitively coupled with the non-moveable portion 802 of the variable capacitor formed on the face of the substrate.

In addition, a coupling structure 804, 805 is provided for matching the impedance of the resonator to a device which can employ the tunable superconducting device. The coupling structure comprises a non-moveable portion including an inductor 804 and a moveable portion 806 of a variable capacitor 805 which are disposed on the face of the substrate so as to be operatively coupled to the tunable superconductor resonator. A second actuator (not shown in Fig. 8), consistent with those illustrated in Figs. 5a and 5b, can also be provided having a moveable end relative to the substrate 101 in response to an applied control voltage. A moveable portion 806 of the coupling structure can be mounted, or otherwise formed, on the moveable end of the second actuator such that the moveable portion 806 of the coupling structure is capacitively coupled with the non-moveable portion 805 of the coupling structure. In this manner, the coupling structure provides a tunable variable capacitor for matching impedance with a device using the tunable superconducting device. An alternative embodiment is possible wherein the coupling structure is provided as a superconductor resonator for higher Q and lower insertion loss. In operation, the first actuator (not shown in Fig. 8) and first moveable part 803 generally have a primary effect on the resonant frequency of the device. The second actuator and second moveable part 806 is adjusted to effect a change in the impedance of the device. Thus, both the resonance frequency and characteristic impedance of the device can be tuned.

The superconducting tunable filter can be used to filter the signal from a conventional receiver or pre-amplifier to get higher signal-to-noise ratio and lower

insertion loss. The tunability of the superconducting tunable filter can be used in a base station of a cellular communication network which needs high sensitivity and swift channel switching and in a magnetic resonance imaging (MRI) probe needs high sensitivity and may need swift frequency switching for sensing resonance signals of nuclei with different spins.

The superconducting tunable resonator can be used as an MRI probe thereby allowing one to tune the resonant frequency of the receiver from one magnetic resonance frequency of a particular nuclear spin to that of another without changing probes. The variable capacitor in the superconducting tunable resonator can be adapted to match the capacitance of the resonator in the MRI detection circuit to realize electric-controlled matching.

With regard to fabrication of an exemplary embodiment of a tunable superconductor resonator in accordance with the invention, the substrate is a two-inch lanthanum aluminate (LAO) wafer substrate having a thickness of about 20 mils. A suitable material for the superconductor is yttrium-barium-copper oxide (YBCO) which is deposited as a layer with a thickness of 200 nm on the substrate. The YBCO film can be deposited on the substrate at a temperature in the range of 700-800°C using laser ablation or a sputtering deposition method. The LAO substrate and YBCO material are available from several commercial vendors, including Dupont. The YBCO material is superconducting at temperatures up to approximately 77 degrees K.

LAO is a preferred substrate material when YBCO is used to form the superconductor layer structure because of high compatibility in lattice matching between these materials respective crystalline structures. Other suitable substrate materials include magnesium oxide (MgO) and strontium titanate (STO).

An exemplary resonator, such as illustrated in Fig. 1, can be formed using a YBCO film on a clean LAO substrate, by a photo-lithographic patterning process according to the following procedure. First, a photoresist, such as Microposit S1813, manufactured by Shepley of Marlborough, Massachusetts, is applied to one side of the substrate which is then spun initially at 300 rpm for 5 sec and then at 4500 rpm for 50 seconds to establish a substantially uniform film. The substrate is then heated at about 120°C for 1 minute to dry the film.

After the substrate is allowed to cool, a positive photo mask of the resonator pattern is used to mask the photoresist coated YBCO film. The exposed photoresist coated YBCO film is then subjected to exposure with UV-light through the photomask at a power of 150 mJ/cm^2. The exposed photoresist on the YBCO film are placed in a developer solution, such as Microposit MF321, manufactured by manufactured by Shepley of Marlborough, Massachusetts, for 1 minute at room temperature. Once developed, the resonator pattern can be realized by etching away the areas of the YBCO film under the exposed photoresist in dilute 1% phosphoric acid solution, available from Olin Microelectronic Material, Inc. of Norwalk, Connecticut, for 80 seconds for a 300 nm layer of YBCO.

The substrate should then be cleaned to remove any remaining photo resist. This can be accomplished by placing the substrate in a solvent, such as acetone, for approximately 2 minutes. To protect the superconductor spiral structure formed on one side from subsequent etching while forming the input and output structures on an opposite side, a protective layer of photoresist can be applied, dried, exposed and developed, as described above.

The following steps can be employed for forming contact pads on either side of the substrate. The substrate side is cleaned to remove dirt and any photo- resist. Next, photoresist is applied, spun, dried, and exposed, in a manner substantially the same as described above, except that a negative mask is used for the contact pads. Alternatively, a contact mask pad can be made of aluminum foil if done carefully. The substrate is then submerged in chlorobenzene for 50 seconds and is then developed, as described above. A metallic coating is formed on the contact areas which were cleared by developing the exposed photo resist by depositing 200 nanometers of Ag and then 100 nanometers of Au. A lift off process can then be employed to remove the unexposed superconductor, such as by using acetone. If annealing is desired, the resulting structure can be annealed in a pure oxygen, O_2, environment at 520 - 550°C atmospheric pressure for 5 minutes. Gold wires can be bonded to the contact pads using a wire bonder. For optimal contact, the wafer should be heated to 120°C.

Fabrication of the moveable portion of the superconducting resonator

can be provided according to the process described above and connected, or otherwise formed, on the moveable end of the actuator according to conventional methods.

Although the present invention has been described in connection with specific exemplary embodiments, it should be understood that various changes, substitutions and alterations can be made to the disclosed embodiments without departing from the spirit and scope of the invention as set forth in the appended claims.

CLAIMS

1. A tunable superconducting resonator comprising:

a substrate having a first face;

first and second superconductor resonator elements on the first face and being electromagnetically coupled; and

a switch circuit coupled to at least one of the first and second resonator elements, the switch circuit providing a signal having at least first and second states, at least one of the states driving at least one of the first and second superconductor resonator elements to a non-superconductive state.

2. The tunable superconducting resonator of claim 1 wherein the second superconductor resonator elements is formed on a first face of a second substrate.

3. The tunable superconducting resonator of claim 1 wherein the first and second superconductor resonator elements are each comprised of a coiled interdigitated capacitor.

4. The tunable superconducting resonator of claim 1 wherein the switch circuit is a superconductor switch circuit.

5. The tunable superconducting resonator of claim 1 wherein the first and second superconductor resonator elements are each comprised of yttrium-barium-copper oxide.

6. The tunable superconducting resonator of claim 5 wherein the switch circuit is comprised of yttrium-barium-copper oxide.

7. A method of active frequency switching for a superconducting resonator comprising:

providing at least first and second superconductor resonator elements operating in a superconducting state and electromagnetically coupled with each other thereby forming the superconducting resonator with a first resonant frequency; and

applying an electrical control signal to at least one of the first and second resonator elements thereby driving at least one of the first and second superconductor resonator elements into a non-superconducting state thereby tuning the superconducting resonator to a second resonant frequency.

8. A tunable superconducting resonator comprising:

a substrate having a first face;

a superconductor resonator element having a non-moveable portion and a moveable portion, the non-moveable portion of the superconductor resonator element comprising an inductor formed on the first face and a portion of a variable capacitor also formed on the first face; and

an actuator having a moveable end relative to the substrate in response to an applied control signal, the moveable portion of the superconductor resonator element being mounted on the moveable end of the actuator and in capacitive communication with the portion of the variable capacitor formed on the first face.

9. The tunable superconducting resonator of claim 8, wherein the superconductor resonator element is comprised of yttrium-barium-copper oxide.

10. The tunable superconducting resonator of claim 8, wherein the actuator is a piezoelectric actuator.

11. The tunable superconducting resonator of claim 10, wherein the piezoelectric actuator is a multilayer bender actuator.

12. The tunable superconducting resonator of claim 10, wherein the piezoelectric actuator is a tube actuator.

13. The tunable superconducting resonator of claim 8, wherein

the portion of the variable capacitor formed on the first face comprises at least one first trunk having a first plurality of tines; and

wherein the moveable portion of the superconductor resonator comprises at least one second trunk having a second plurality of tines and being in moveable juxtaposition with the first tines of the portion of the variable capacitor.

14. A tunable superconducting filter comprising:

a substrate having a first face;

a plurality of superconductor resonator elements, each of the plurality of superconductor resonator elements having a non-moveable portion and a moveable portion, the non-moveable portion of comprising an inductor formed on the first face and a portion of a variable capacitor also formed on the first face;

a plurality of actuators, each of the plurality of actuators having a moveable end relative to the substrate in response to an applied control signal, the moveable portion mounted on the moveable end of the actuator and being in capacitive communication with the portion of the variable capacitor formed on the first face;

at least one input coupling structure disposed on the first face of the substrate, the at least one input coupling structure being operatively coupled to at least one of the plurality of superconductor resonator elements; and

at least one output coupling structure disposed on the first face of the substrate, the at least one output coupling structure being operatively coupled to at least one of the plurality of superconductor resonator elements.

15. The tunable superconducting filter of claim 14, wherein each inductor of the plurality of superconductor resonator elements has an elongate geometry with a first end and a second end, and the inductors being arranged in a substantially side-by-side relationship.

16. The tunable superconducting filter of claim 15, wherein at least one of the first ends is offset from the first end of an adjacent inductor.

17. The tunable superconducting filter according to claim 15, wherein the moveable and non-moveable portions of each superconductor resonator elements are comprised of yttrium-barium-copper oxide.

18. The tunable superconducting filter according to claim 15, wherein the at least one input coupling structure and the at least one output structures comprise metallic inductor elements.

19. The tunable superconducting filter according to claim 15, wherein the at least one input coupling structure and the at least one output coupling structure are formed from a superconducting material.

20. The tunable superconducting filter according to claim 15, wherein each of the plurality of superconductor resonator elements are resonant at substantially the same frequency.

21. The tunable superconducting filter according to claim 15, wherein the plurality of superconductor resonator elements are resonant at a plurality of frequencies, each of the plurality of frequencies corresponding to one of the at least one output coupling structures.

22. A tunable superconducting device comprising:

a substrate having a first face;

a tunable superconductor resonator element having a non-moveable portion and a moveable portion, the non-moveable portion comprising an inductor formed on the first face and a portion of a variable capacitor also formed on the first face;

a first actuator having a moveable end relative to the substrate in response to an applied control signal, the moveable portion of the tunable superconductor resonator element mounted on the moveable end of the actuator and being in capacitive communication with the portion of the variable capacitor formed on the first face;

a coupling structure having a non-moveable portion and a moveable portion, the non-moveable portion disposed on the first face of the substrate and being operatively coupled to the tunable superconductor resonator element; and

a second actuator for impedance matching of the tunable superconductor resonator element having a moveable end relative to the substrate in response to an applied control signal, the moveable portion of the coupling structure mounted on the moveable end of the second actuator and the moveable end being in capacitive communication with the coupling structure.

23. The tunable superconducting device of claim 22 wherein the coupling structure is a second superconductor resonator element.

Fig 1

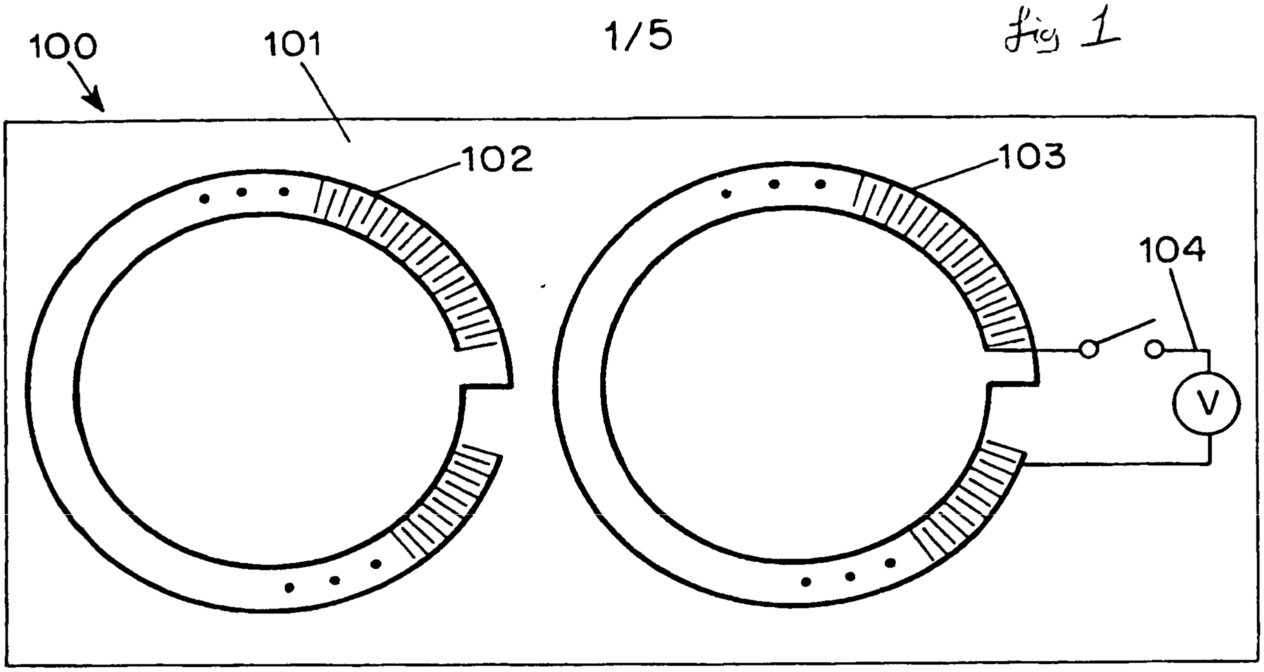

FIG. 1

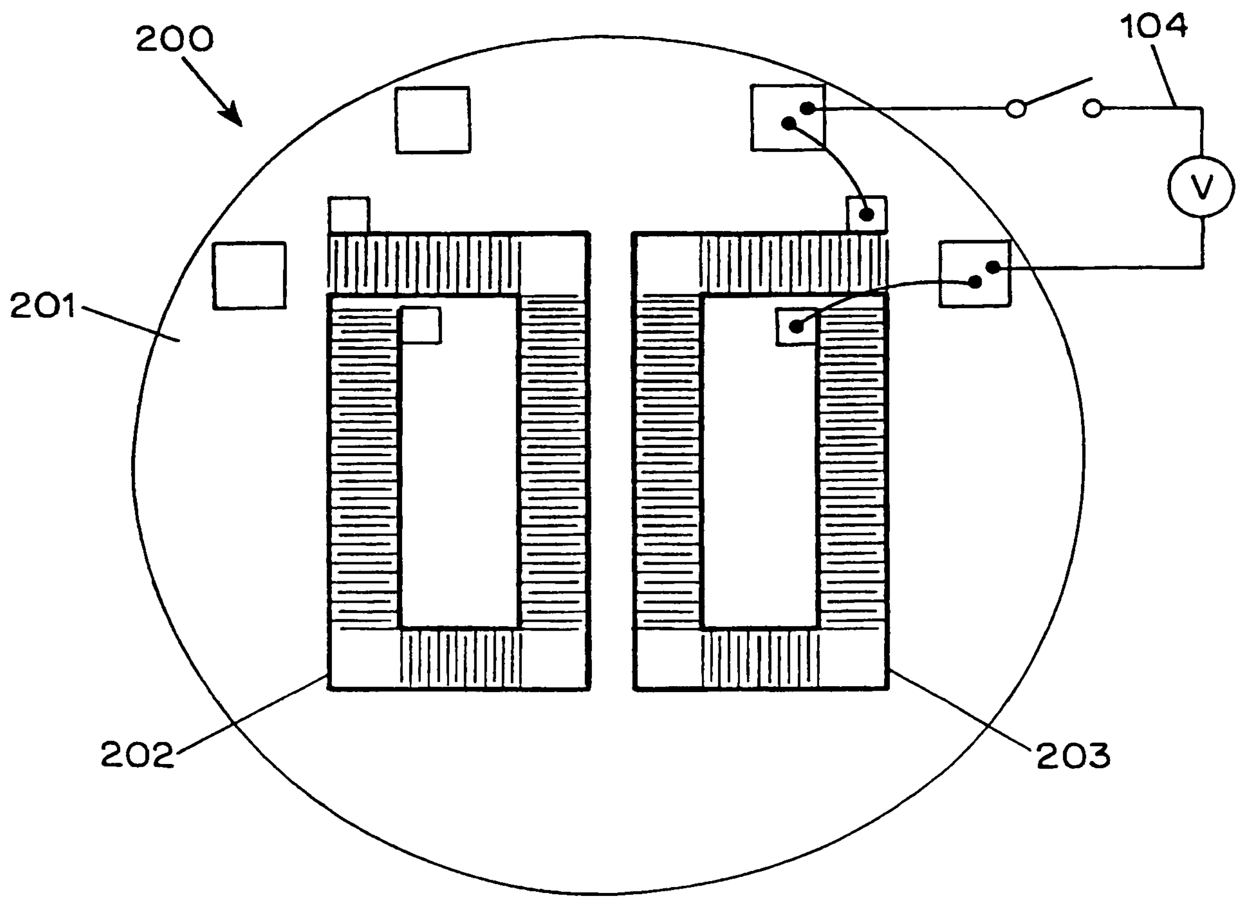

FIG. 2

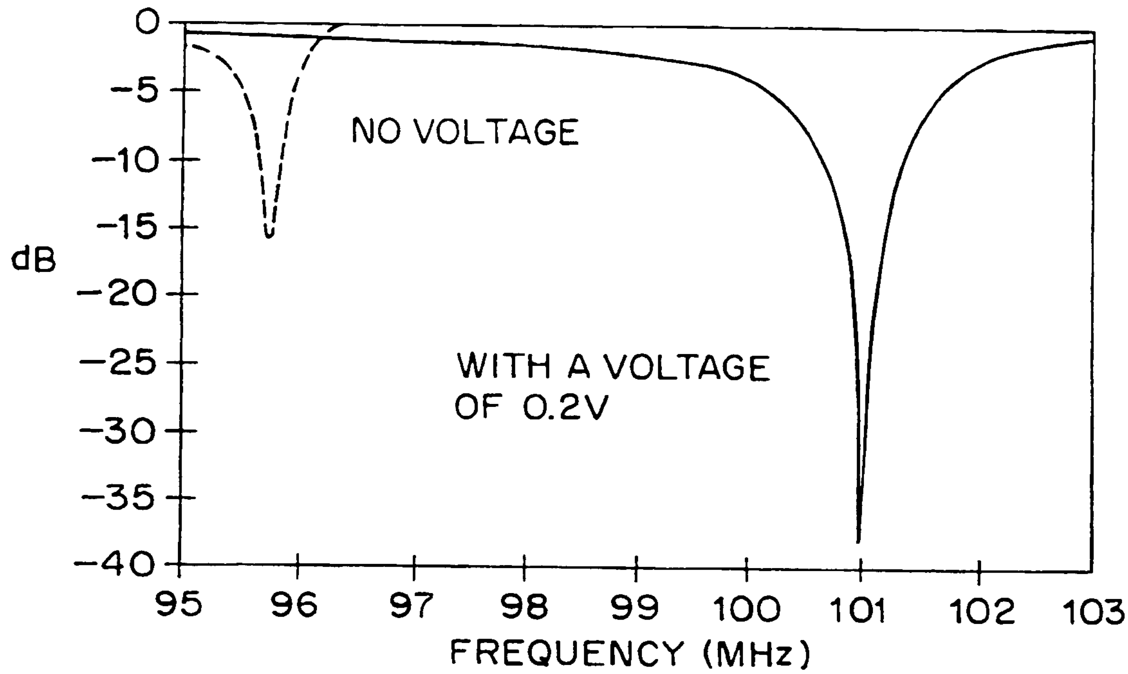
0
-5
-10
-15
dB
-20
-25
-30
-35
-40
95
96
97
98
99
100
101
102
103
FREQUENCY (MHz)
NO VOLTAGE
WITH A VOLTAGE
OF 0.2V

FIG. 3

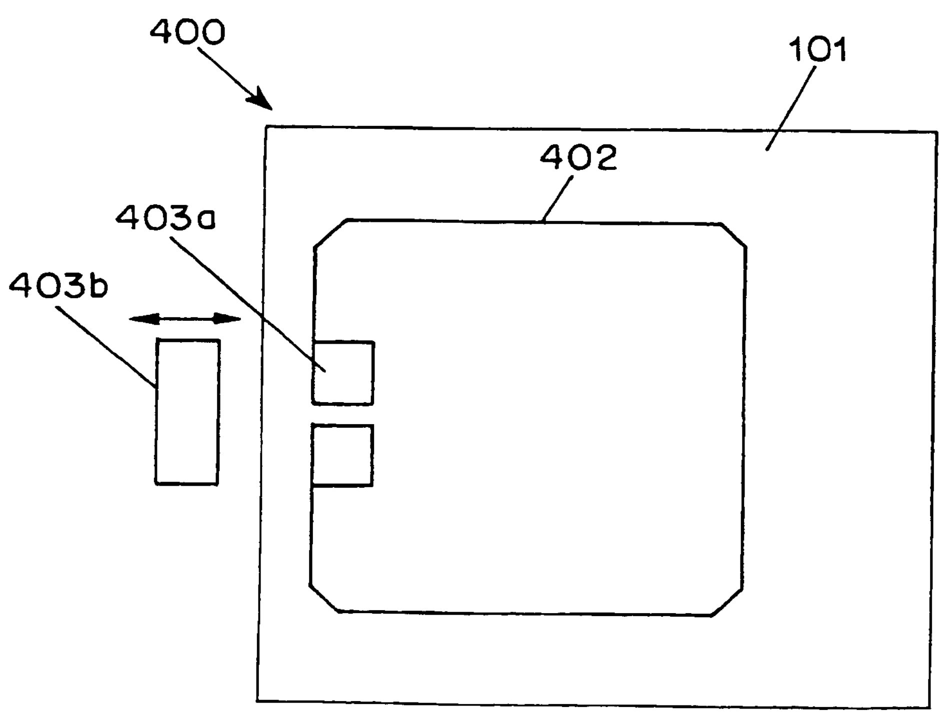
400
101
402
403a
403b

FIG. 4

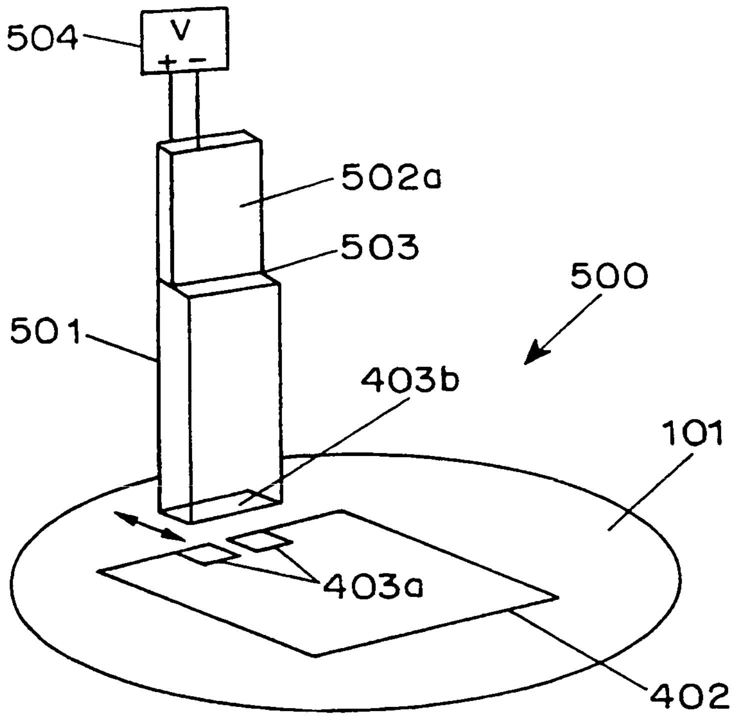
504
V
+ -
502a
503
500
501
403b
101
403a
402

FIG. 5a

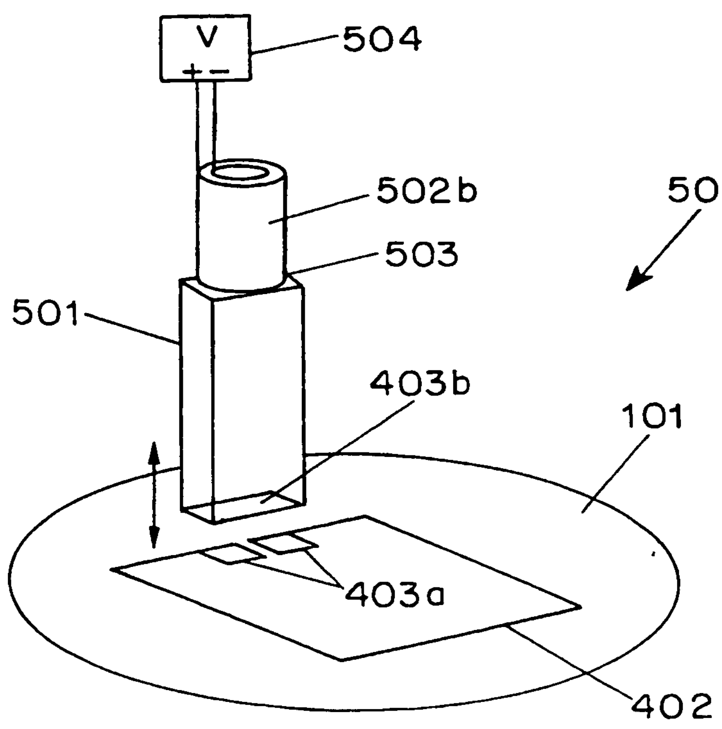
V
+ -
504
502b
500
503
501
403b
101
403a
402

FIG. 5b

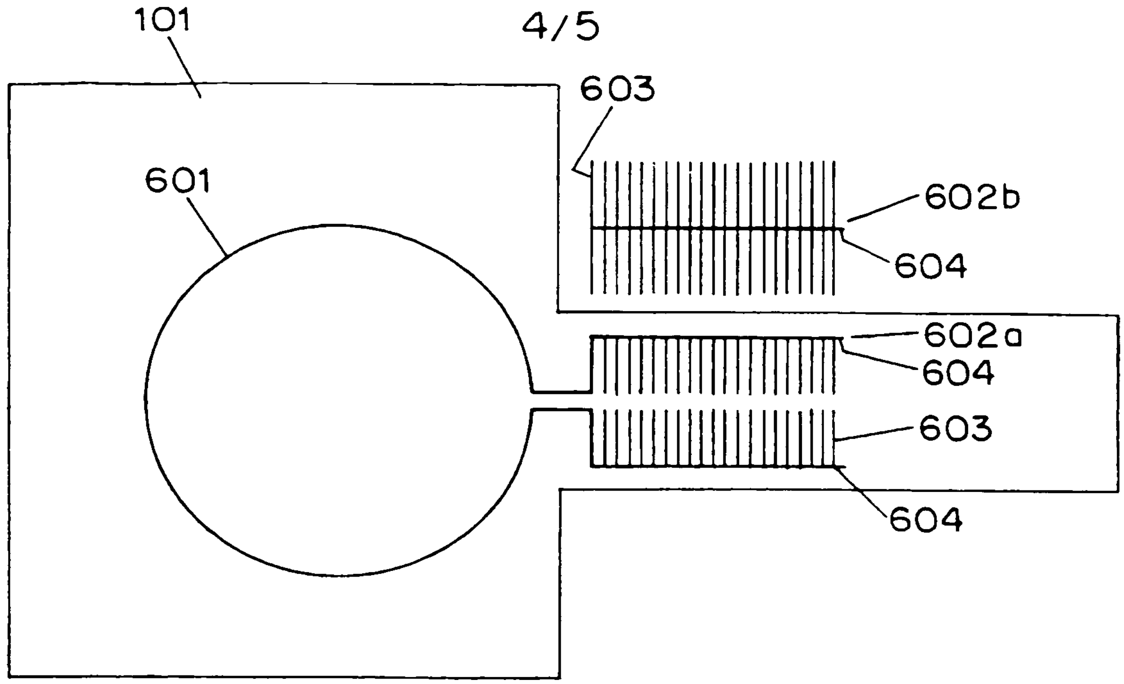
101
603
601
602b
604
602a
604
603
604

FIG. 6

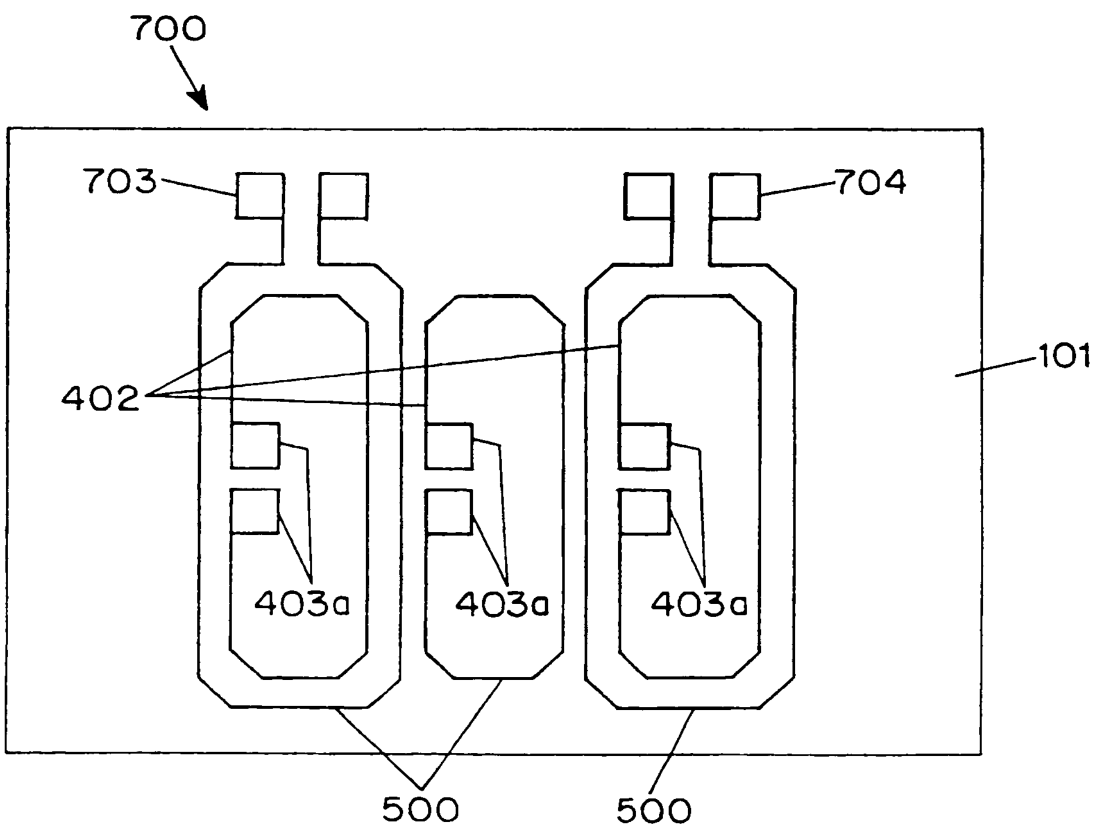
700
703
704
402
101
403a
403a
403a
500
500

FIG. 7

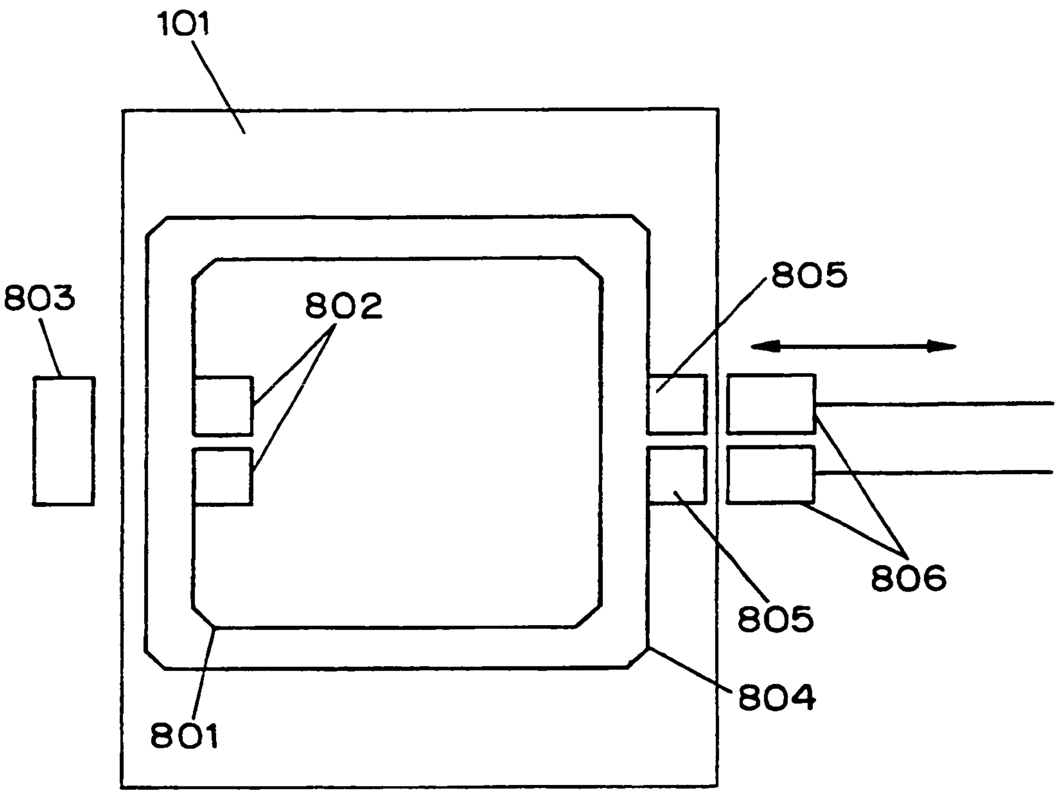

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/40457

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H01P 1/203, 7/08; H01B 12/02
US CL :505/210, 700, 701, 866; 333/99S, 205, 235
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 505/210, 700, 701, 866; 333/99S, 205, 219, 235, 262

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- A	US 5,912,472 A (VOIGHTLAENDER ET AL) 15 June 1999 (15/06/99), see figs. 2b & 5 and description of these figures.	1, 4-6; 7 ------------ 2; 8-13; 14-21; 22,23
X -- A	JP 2-101801 A (INAHATA) 13 April 1990 (13.04.90), see abstract & fig. 1.	1, 5; 7 ---------- 2-4, 6; 8-13; 14-21; 22,23

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 NOVEMBER 2000	11 DEC 2000

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